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GEOLOGY.—*Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands, and notes on eastern Porto Rico.*[1]

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INTRODUCTION

The present paper briefly summarizes some of the results obtained from a geologic reconnaissance I made of the islands of St. Croix, Saint John, Saint Thomas, Culebra, and Vieques and of the eastern

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end of Porto Rico in compliance with a request made by the Navy Department for special geologic information on the territory examined. The field work was done between May 21 and June 24, 1919. The collections made were examined by the following of my official colleagues: Mr. C. P. Ross examined the igneous rocks; Dr. T. W. Stanton identified the Cretaceous mollusks; Dr. J. A. Cushman identified the Tertiary Foraminifera; Dr. R. S. Bassler, the Bryozoa; and Dr. C. W. Cooke, the Tertiary Mollusca. The corals were identified by me.

LOCATION AND GENERAL FEATURES

The Virgin Islands, except Saint Croix and its outlying islets, rise above a shallow bank that extends northeastward from Porto Rico to Anegada Passage. The number of the islands is about 100. They are separated from one another and from eastern Porto Rico by water having a maximum depth of 16 to 18 fathoms. Except Anegada which rises only about 30 feet above sea level, the larger islands attain altitudes ranging from about 650 feet (Culebra) to 1800 feet (Tortola) in altitude. The highest point in Saint John is 1,277 feet; in Saint Thomas, 1,550 feet; in Culebra, 650 feet; in Vieques, 981 feet. The islands are well dissected and as a rule have gradual slopes, except along the shores where there may be high sea-cliffs. The absence of inland bluffs is one of the striking features of the topography of these islands. The shore line is indented by bays, which indicate geologically Recent submergence.

The Virgin Bank is about 90 sea miles long and from 24 to 30 sea miles wide. The depth of water on it is as much as about 40 fathoms around its edges where there are steep descents to deep water, to over 3,000 fathoms between Saint Thomas and Saint Croix, to about 1,200 fathoms in Anegada Passage, and to 400 fathoms on the north side, where there is an apparently gradual slope to depths of about 3,600 fathoms at a distance of about 55 sea miles north of the bank. Along a line about 25 sea miles long through the Virgin Passage the depth ranges from 12 fathoms in the shallowest part to about 40 fathoms on the northern edge—the range in relief on the flat being only about 132 feet in about 25 miles. The surface of the bank exhibits submarine terraces both off the shores of Saint John and Saint Thomas and in the Virgin Passage. The living coral reefs have grown up on the terraced surface of the bank after an episode of submergence, a relation which I have described in several papers.

Between the Virgin Bank and Saint Croix there is a deep of 3,400 fathoms which is continuous eastward into Anegada Passage, whose

depth is over 1,000 fathoms. The maximum altitude in Saint Croix is 1,164 feet, the top of Mount Eagle. The higher land is dissected and has gradual slopes similar to those mentioned for the islands on the Virgin Bank, but Saint Croix is peculiar in that in its southwestern part there is an extensive, gently sloping limestone plain. The shore line features are indicative of submergence as in the case of the other islands.

STRATIGRAPHY

In the Virgin Islands three major sets of rocks may be recognized as follows: (1) Upper Cretaceous sediments and interbedded volcanic tuffs, breccias, and lava flows; (2) Post-Cretaceous, probably early Tertiary, intrusive gabbro, dolerite, diorite, and quartz-diorite, and perhaps also volcanic extrusions; (3) Oligocene and Miocene marls and limestones.

Upper Cretaceous Rocks

Saint Croix

The older rocks of Saint Croix are exposed in the northwestern part of the island and they occupy the entire area east of Christiansted. They comprise sandstone, shale, and limestone, with interbedded volcanic tuffs. A very instructive exposure may be studied at Waiter's Point. On the east side of this point there are thinly bedded sandstone and shale, west of which is limestone interbedded with volcanic tuff. Quin published notes on the exposure at this place and collected Cretaceous fossils there, but he did not know the biologic affinities of the fossils or their geologic significance. The Misses Quin presented to me, for transfer to the United States National Museum, all of their father's collection and I collected an additional species. Dr. T. W. Stanton supplies the following list of species from Saint Croix:

Inoceramus sp., related to *I. proximus* Tuomey.
Barrettia monilifera Woodward.
Barrettia sparcilirata Whitfield?
Radiolites nicholasi Whitfield.
Caprinula gigantea Whitfield?
Caprinella occidentalis Whitfield.

There is no room for doubt as to the geologic age of the deposits from which these fossils come—it is Upper Cretaceous.

The interbedding of volcanic tuff with the limestone has been mentioned.

Saint Thomas

The presence of sediments of Upper Cretaceous age in Saint Thomas was first recognized by Cleve in 1869, when he collected a moderate number of fossils and recognized the affinities of the fauna with that of Gosau, Austria. Some years ago Professor A. G. Högbom of the University of Upsala lent me the Cleve collection and Doctor Stanton listed for me the genera of the fossils. They are as follows:

Glycymeris
Limopsis
Astarte, several species
Opis
Cyprina?
Corbula
Cerithium, two or more species
Nerinea, several species
Actaeonella
Phylloceras?, immature, septa not well shown.

It seems that I did not rediscover the precise spot at which Cleve obtained his specimens; however, I collected at Coki Point, one of the localities mentioned by Cleve, poorly preserved fossils that seem to represent the genera *Astarte*, *Glauconia*, *Cerithium*, and *Actaeonella*. The fauna is clearly the one discovered by Cleve. The fossils occur in very hard, blue, metamorphosed limestone. At a locality near Coki Point, limestone belonging to the same formation contains some volcanic material and is associated with, probably interbedded with, shaly rocks that have been metamorphosed into schists.

The principal country rock of Saint Thomas comprises andesitic breccia and latite, which in places shows rude bedding. I did not actually observe the relations of these rocks to the Cretaceous limestone, but the older volcanic rocks have been considerably metamorphosed. It is to rocks of this kind that the local name "blue-beach" is applied. Cleve says that he found north of Bucks Bay "blue-beache, black and sometimes metamorphosed clay slate, and flagstone, alternating;" and he says that near Coki Point the blue beach contains "calcareous nodules and marble of a white or gray color." The older volcanic rocks, therefore, seem to be of Upper Cretaceous age.

Saint John

Except large rounded, apparently water-worn boulders about half a mile east of Government House, Little Cruz Bay, the only rocks I saw on Saint John are clearly of igneous origin. The rocks at Coral Bay are chlorite and sericite schists and are inferred to be of Cretaceous or more ancient age, because of the metamorphism they have undergone. Cleve mentions greatly metamorphosed limestone at

Anna Bay (probably meaning Anna Berg). Although paleontologic evidence is not available for Saint John, the lithologic characters are such as to leave no reasonable doubt of the presence on it of both Cretaceous sedimentary and volcanic rocks as on Saint Thomas, which is only about one and a half miles from the west end of Saint John, and there may be rocks of pre-Cretaceous age.

Culebra

Metamorphosed sedimentary rocks composed of reworked volcanic constituents were seen in the valley north of San Ildefonso; southwest of Swell Bay at altitudes below 200 ft.; on the point of land on both the east and west sides of Surf Bay; west and north of Great Harbor; and at Playa Sardinos. On the basis of their lithologic characters it seems safe to refer these rocks to the Upper Cretaceous.

Vieques

The oldest rocks observed on Vieques comprise a trachytic lava flow, overlain by limestone conglomerate, over which is an altered basalt, which in turn is overlain by hard blue limestone. This exposure is at Punta Diablo. The dip of the limestone is as high as 60°. Bedded rock of shaly or sandy appearance, which is probably water-laid tuff, was seen at many places. Because of its lithologic characters, its deformation, and its metamorphism, this group of rocks is considered of Upper Cretaceous age.

Eastern Porto Rico

Examination was made of bedded sandstones and shales, which are composed of water-laid volcanic material, in the vicinity of Fajardo and of a folded basalt flow at Cape San Juan. These sediments and their associated igneous rocks, which are cut by great dikes of dolorite, would be referred to the Upper Cretaceous according to the criteria I have applied in Culebra and Vieques. They evidently represent what Hill described as "black or other dark-colored basic igneous rocks, occurring as tuffs, conglomerates, and sills of hornblende-andesite, cut by dikes of diorite."[2] Hill found associated with these rocks limestone in which he collected fossils that Dr. T. W. Stanton identifies as belonging to the Capriniidae and considers representative of the Upper Cretaceous. Berkey's[3] descriptions of the rocks exposed

[2] Hill, R. T., Notes on the forest conditions of Porto Rico: U. S. Dept. of Agriculture, Division of Forestry Bull. 25: 14–15. 1899.

[3] Berkey, C. P., Geological reconnaissance of Porto Rico: New York Acad. Sci. Ann. 26: 1–70. 1915.

around Fajardo are correct, but he gives no data of assistance in determining their geologic age.

Summary statement on Cretaceous rocks.—Fossiliferous Upper Cretaceous sediments interbedded with volcanic rocks occur in Saint Croix and Saint Thomas. Sediments with interbedded or associated volcanic rocks similar to those of Saint Croix and Saint Thomas are present in Saint John, Culebra, Vieqeus, and eastern Porto Rico, and because of similar lithology and similar deformational history are considered of Upper Cretaceous age.

Early Tertiary Events

Subsequent to the deposition of the Upper Cretaceous sediments and the extrusions of the associated volcanic rocks, there was intense deformation, which resulted in tight folding in Saint Croix, where dips of 80° or more are common; the dips in Saint John are about the same; in Saint Thomas they are 50° or more; in Culebra I noted some low dips, only 19°; in Vieques the dips are as much as 60°; in eastern Porto Rico the range is from about 13° to almost vertical. Some of the older igneous rocks, which in many instances have been so crushed that they are now chlorite or sericite schists, may be of pre-Cretaceous age. The structure lines cannot be described at this place—only the general statement may be made that in places there are intersecting trends, one approximately east and west and another from northwest to southeast. The two sets of trends are very clearly recognizable in Saint Thomas. There were extensive intrusions of diorite, dolerite, and quartz-diorite, and probably also extrusions of lavas and tuffs. Quartz-diorite is the dominant rock in Vieques. The older series of rocks was subjected to subaerial erosion for so long a time that over considerable areas they were practically base-leveled and the next younger sediments were laid down on a nearly plain surface developed on rocks that dip as steeply as 80°, as in the southwestern part of Saint Croix.

Tertiary Sediments

Sediments of Tertiary age are present in Saint Croix, Vieques, and eastern Porto Rico but appear to be entirely absent on Saint John, Saint Thomas, and Culebra. In fact, except Anegada, there are no known Tertiary sediments on the axial islands of the Virgin group, and in Porto Rico such younger deposits are confined to the northern and southern flanks of the island. Therefore the axial islands of the Virgin Bank and the sierras of Porto Rico appear to have been above water since the close of Cretaceous or since very early Tertiary time.

Saint Croix

In Saint Croix Tertiary limestones and marls cover an area reaching the southern shore south and southeast of the hills in the northwestern part of the island, they extend northward to the north shore just east of the mouth of Salt River, whence the eastern boundary runs southward to the west side of Waiters Point. In general the limestones are soft, rather crumbly, and there are interbedded layers of conglomerate. The dips are in general southward, at angles ranging from 8° to 15°—strongly contrasting with the steep dips, in places 80° or more, of the Cretaceous rocks.

Three horizons seem to be represented in these limestones, viz., (1) middle Oligocene, (2) probably upper Oligocene, (3) lower Miocene.

Middle Oligocene

Station 8649. Two-tenths of a mile southwest of Wheel of Fortune estate house; collection made on northern slope of a low hill.

Foraminifera:

Rotalia sp. Abundant
Amphistegina sp. Compare with station 8648.
Lepidocyclina morgani Lemoine and R. Douvillé. Also Cuba.
Carpenteria americana Cushman. Also Cuba.

Madreporaria:

Astrocoenia decaturensis Vaughan. Also Antigua; Bainbridge, Ga.
Gomiastrea reussi (Duncan). Also Antigua.
Cyathomorpha tenuis (Duncan). Also Antigua; Pepino formation of Porto Rico; and other places.
Goniopora microscopica (Duncan). Also Antigua.

Geologic correlation.—The organisms from this locality show clearly that the geologic horizon is the same as that of the Antigua formation of Antigua, for every coral well enough preserved for specific identification also occurs in Antigua, and that it is, therefore, middle Oligocene.

Probably upper Oligocene

Station 8647. One and four-tenths sea miles in a straight line from Christiansted lighthouse, on the south side of North Shore road at Evening Hill.

This is the locality at which Quin[4] says he found large Foraminifera. The rock as exposed in the road is an argillaceous limestone, mostly rather soft but there are indurated lumps and beds. The fossils comprise some well preserved nummulitoid Foraminifera and indetermin-

[4] Quin, John T., The building of an island, p. 17, 1907.

able fragments of corals. The names of the Foraminifera are as follows:

Amphistegina sp.
Heterostegina antillea Cushman. Also Antigua and northeastern Mexico.
Heterosteginoides sp. cf. *H. antillea* Cushman. Also Anguilla.

Station 8648. North Shore road, Montpellier (east).

The rock here exposed is a rather soft, spongy, impure limestone. The contained organic remains include determinable Foraminifera and indeterminable corals and mollusks. The geologic formation seems the same as that exposed at station 8647. The Foraminifera are as follows:

Amphistegina sp. Compare above, station 8647.
Peneroplis sp.
Gypsina globulus (Reuss). Also Anguilla; Recent.

Geologic correlation.—There seems to be no reasonable doubt that the same formation is exposed at both Evening Hill and on the North Shore road at Montpellier (east). The geologic horizon is either middle or upper Oligocene, more probably upper Oligocene.

Station 6850. Montpellier (east), collected by John T. Quin. The specimen referred to by Quin as a volute[5] is a species of *Orthaulax* which seems to be the same as a species of *Orthaulax* I collected at Crocus Bay, Anguilla, now identified as *O. aguadillensis* Maury. The specimen from Saint Croix was presented to me for transfer to the United States National Museum by the Misses Quin, the daughters of the author of "The building of an island," and I had a number of sections cut of the matrix. Foraminifera are abundant and Doctor Cushman furnishes the following list:

Alveolina sp. Also Saint Martin.
Orbitolites duplex Carpenter? Also Saint Martin.
Spiroloculina sp. Also Saint Martin.
Also indeterminable species of *Quinqueloculina*, *Triloculina*, *Globigerina*, and *Amphistegina*.

Geologic correlation.—The presence of the species of *Orthaulax* above noted suggests upper Oligocene, about the horizon of the Anguilla formation, as the age of the bed from which the specimen came. Doctor Cushman says that the Foraminifera are precisely the same as those I collected in the yellowish limestone of Saint Martin. The horizon may be very low Miocene instead of topmost Oligocene.

[5] Quin, John T., The building of an island, plate opposite page 16, 1907.

Miocene

Station 6851. Anna's Hope estate, along the road.

Foraminifera:

Clavulina sp. cf. *C. parisiensis* d'Orbigny. Also Culebra formation.
Clavulina sp. cf. *C. communis* d'Orbigny. " " "
Nodosaria sp. cf. *N. insecta* Schwager. Culebra formation.
Uvigerina sp. (?)
Orbulina sp.
Globigerina sp.
Truncatulina wuellerstorfi Schwager. Culebra formation also Recent.
Siphonina sp. cf. species from Oligocene of the United States.
Pulvinulina sp. cf. species from Oligocene of the United States.
Asterigerina sp. cf. species from Oligocene of the United States.
Amphistegina sp.
Ellipsoidina sp.

Madreporaria:

Obicella sp. cf. a species from the lower Miocene of Trinidad and Vieques Island.
Psammocora sp. cf. a species from the Miocene of Trinidad. Other species of this genus are known from the lower Miocene of Trinidad, Vieques Island, and the Dominican Republic.

Geologic correlation.—The basis for correlating this deposit is not definite, but the horizon seems to be very low Miocene.

Vieques Island

At Punta Salinas, east of Port Salinas and Salina del Sur, at the east end of the island, and along the south shore from opposite Esperanza to Enseñada de la Chiba, there is soft, light-colored, usually yellowish, bedded, fossiliferous limestone, which although slightly tilted and in places flexed, has been, in comparison with the older hard blue limestone, only slightly disturbed. Between Enseñada Sombe and Port Mosquito, between Port Mosquito and Port Ferro, and on the east side of Port Ferro, steep, northward-facing slopes mark the northern edges of the areas of its outcrop. The following are the paleontologic determinations for Vieques:

Station 8652. Vieques Island, north side, east end, the westernmost of the yellow marl and limestone bluffs at the east end of the island.

Foraminifera:

Gaudryina triangularis Cushman. Also Yumurí River, Cuba, U. S. G. S. 3461, and 6010, Culebra formation, Panama Canal Zone; Recent.
Verneuilina spinulosa Reuss. Also Yumurí River, Cuba, U. S. G. S. 3461; Recent.

Chrysalidina pulchella Cushman? Also U. S. G. S. Station, 6036 Gatun Formation, Panama Canal Zone.

Discorbis bertheloti (d'Orbigny). Also Choctawhatchee marl, one mile south of Red Bay, Fla.; Recent.

Truncatulina americana Cushman. Also Miocene of Coastal Plain, U. S.; upper part of Culebra formation, Panama Canal Zone; and Oligocene of Coastal Plain, U. S.

Truncatulina wuellerstorfi (Schwager) ? Miocene of Coastal Plain, U. S.; Oligocene of Panama Canal Zone; Recent.

Truncatulina lobatula (Walker and Jacob.) Also 3461, Yumurí River, Cuba; Cercado de Mao, Dominican Republic; Recent.

Pulvinulina menardii (d'Orbigny)? Also 6033–35–36, Gatun Formation, Panama Canal Zone; Recent.

Gypsina globulus (Reuss) var. *pilaris* H. B. Brady. Also Bowden, Jamaica; Anguilla?; Recent.

Nonionina scapha (Fichtel and Moll.) Also 6033, Gatun Formation, Panama Canal Zone; Recent.

Quinqueloculina seminulum (Linné). Also Gatun Formation and Culebra Formation, Panama Canal Zone; Recent.

Orbitolites duplex Carpenter? Also Anguilla, St Martin; Recent.

Only 2, 83 per cent, of the species above listed are not reported from the living foraminiferal faunas.

Madreporaria:

Stylophora sp.

Orbicella attissima (Duncan). Also Miocene of Trinidad.

Orbicella sp. Also Miocene of Trinidad.

Orbicella or *Solenastrea* sp.

Siderastrea siderea (Ellis and Solander). Range from lower Miocene to Recent.

Psammocora sp. Also Miocene of Trinidad.

Porites sp.

Mollusca:

Ostrea haitiensis Sowerby.

Teredo sp., like *Kuphus incrassatus* Gabb.

Geologic correlation.—The two species of *Orbicella*, and the species of *Psammocora* and *Ostrea haitiensis*, all indicate an old Miocene age, probably older than that of the Bowden marl of Jamaica. *Siderastrea siderea* is not known from deposits older than Miocene and persists today in Caribbean and Floridian waters.

Station 8654. Vieques Island, sea bluff at Cucuracha Light, south side of the island.

Foraminifera:

Gypsina globulus (Reuss). Also Recent.

Asterigina sp.

Orbiculina sp.

Madreporaria:

Solenastrea bournoni Milne Edwards and Haime. Also Recent.

Mollusca:

Turritella sp.
Ostrea sp., probably *O. haitiensis* Sowerby.
Pecten sp., close to *P. ventonensis* Cooke and *P. soror* Gabb but apparently different from both.
Spondylus sp.
"Lucina" sp.
Teredo sp., like *Kuphus incrassatus* Gabb.

Geologic correlation.—That the rocks from which the fossils obtained at Station 8654 are not older than Miocene is shown by the presence of *Solenastrea bournoni;* while the oysters and the *Pecten* indicate that they are as old as Miocene.

Eastern Porto Rico

On the north side of the road from Fajardo to San Juan, about 5 kilometers east of Rio Piedras, there is a low hill composed of argillaceous, yellowish limestone. The following fossils were collected here:

Station 8653. Porto Rico, 5 kilometers east of Rio Piedras, north side of road from San Juan to Fajardo. Collected by T. W. Vaughan.

Foraminifera:

[2] *Asterigina* sp.
[1] *Orbitolites* sp.
[1] *Orbiculina* sp.
[1] *Quinqueloculina* sp.

Madreporaria:

Pocillopora sp., apparently new species related to *P. crassoramosa* Duncan.
Siderastrea sp., apparently new species.
[1] *Porites* sp. or *Goniopœa* sp., of the growth form of *Goniopora clevei*, Vaughan.
[2] *Porites* sp. aff. *P. astreoides* Lamarck
Porites sp.

Bryozoa:

[1] *Holoporella albirostris* Smitt.

Mollusca:

[1] *Teredo* sp., like *Kuphus incrassatus* Gabb.

Geologic correlation.—Either uppermost Oligocene or very low Miocene. The forms whose names are preceded by "1" are known in deposits of both upper Oligocene and lower Miocene age; those preceded by "2" are not known at a horizon below Miocene.

Summary statement on deposits of Tertiary age.—In the foregoing remarks it has been stated that deposits of middle Oligocene (Rupelian) and probably upper Oligocene (Aquitanian) age occur in Saint Croix and that deposits of lower Miocene (Burdigalian) age occur probably in Saint Croix, certainly in Vieques, and probably on the north side of

Porto Rico east of San Juan. As I have given in the final part of Bulletin 103 of the United States National Museum a rather full account of the distribution of marine deposits of these ages, except for the Virgin Islands, Porto Rico, and the island of Haiti, I will not repeat what I published, except in so far as it bears on the problems under discussion.

From corals collected by R. T. Hill in western Porto Rico in 1898 I pointed out in notes published by Hill in 1899 that his Pepino formation is of the same age as the Antigua formation which is now classified as of middle Oligocene (Rupelian) age. In addition to this horizon Miss Maury has recently recognized upper Oligocene and lower Miocene in western Porto Rico. The geologic exploration made for the Military Government during April, May, and June, 1919, in the Dominican Republic has led to the recognition there of upper Eocene, middle Oligocene, upper Oligocene, and six Miocene horizons of which the lowest and the upper three are new—that is, at least seven definable new Tertiary horizons were recognized in the Dominican Republic. South of Santiago, near Baitoa, Condit and Cooke found the basal Miocene resting on the deformed, folded, and eroded surface of middle Oligocene deposits which carry the Antiguan foraminiferal and coral fauna. The specimens of *Lepidocyclina* are equaled in size only by those in Antigua where some are four inches in diameter. The Eocene formations of the Republic of Haiti have been briefly discussed by Woodring in two recent papers.[6] Later the significance of these determinations will be indicated.

Pleistocene deposits

Although I did not land on the Cordilleras reefs, I could see from the subchaser on which I travelled that they are composed of limestone. A specimen of soft limestone from Icacos Key, given me by Mr. Jorge Byrd-Arias, is a very fine-grained oolite. I suppose that this rock is of Pleistocene age from analogy with Florida and the Bahamas.

SUMMARY OF GEOLOGIC HISTORY

(1) The presence of shoal water deposits of Upper Cretaceous age, in Saint Croix and in the islands on the Virgin Bank from Saint John to Porto Rico and in Porto Rico shows that the major tectonic axis of this part of the West Indies antedates Upper Cretaceous time,

[6] Woodring, W. P., Middle Eocene foraminifera of the genus *Dictyoconus* from the Republic of Haiti: this Journal 12: 244–247. 1922; and An outline of the results of a geological reconnaissance of the Republic of Haiti: Ibid. 13: 117–129. 1923.

because there was an antecedent basement on which these deposits were laid down. I have suggested that these major trends may be even as old as late Paleozoic.

(2) During Upper Cretaceous time it is probable that most of, perhaps all of, the areas now occupied by land were under water; and that there was considerable volcanic activity is proved by the water-laid tuffs and lava flows which are interbedded with the shoal-water calcareous sediments.

(3) In early Tertiary, probably Eocene, time there was mountain making by folding which in places was so intense that the stratified rocks were left in an almost vertical position and both the sediments and the older igneous rocks were metamorphosed. There were also intrusions of diorite, dolerite, and quartz diorite, and probably the extrusion of some volcanic rocks. West of the Virgin Islands, there was during later Eocene time extensive submergence in the Dominican Republic, Haiti, and Cuba, as is attested by the Eocene formations now above sea-level in those areas.

(4) The episode of mountain making was followed in the Virgin Islands by one of prolonged subaerial erosion, and the production of the Virgin Bank apparently may in large part be assigned to this period of the history of the region. It seems that the axial islands on the Virgin Bank and the Central Sierras of Porto Rico, from its east to its west end, have continuously stood above the water since the close of Cretaceous deposition. In Saint Croix by middle Oligocene time erosion had proceeded far enough to reduce almost to base level the tightly, steeply folded strata of the mountains.

(5) In middle Oligocene time a large part of Saint Croix wes submerged and, with slight fluctuations, remained under water until sometime during the Miocene. Although both the northern and southern, but not the axial, parts of western Porto Rico were submerged in middle Oligocene, and probably in lower Oligocene time, the eastern end of Porto Rico and the axial islands of the Virgin Bank west of Anegada Island were not submerged. The age of the limestone on Anegada Island is not known. These facts mean that there was differential movement, the movement being greater toward the west than in the central part of the bank. In lower Miocene time the northern shore of Porto Rico east of San Juan was submerged as were also the southern shore and eastern end of Vieques Island—both the northern and the southern edges of the bank were submerged probably by marginal down flexing. Although there are corals in the exposed sediments of Oligocene and Miocene age, and corals were therefore constructional agents during those epochs, their work as compared with

that of other agents was of minor importance. If the work of these organisms in forming deposits concealed under water can be evaluated by their work in deposits exposed to view, the conclusion would be drawn that they played only a minor rôle in the formation of the Virgin Bank. There is as yet no evidence showing intense deformation during later Oligocene time in the Virgin Islands and Porto Rico such as is known to have taken place in the Dominican Republic.

(6) Subsequent to early Miocene time there has been uplift, greater along the axis of Porto Rico and the Virgin Bank than on the flanks, bringing Miocene and older Tertiary sediments, in places where they are present, above sea level. The Tertiary sediments are tilted and gently flexed but they have not been so much deformed as the Upper Cretaceous deposits. It is about this time that the land connections permitting migration of land animals from Anguilla to Porto Rico, Haiti, and Cuba seem to have existed. Saint Croix seems to have been connected with Anguilla, Saint Martin, and Saint Bartholomew.

(7) The period of high stand of land was followed by faulting, such as I have several times described recently; but, as pointed out by Woodring, the faulting was concomitant with folding. By these processess Anegada Passage between the Virgin Bank and Anguilla was produced and the islands assumed very nearly the outlines and arrangements of today.

(8) Subsequent to the episode of faulting there was emergence of the land, and terracing of the margins of the Virgin Bank, followed by submergence. In places in Porto Rico and along the Cordilleras reef, which extends eastward from the northeast corner of Porto Rico, there has been local emergence due to differential crustal movement.

(9) The living coral reefs on the Virgin Banks are growing on an extensive flat in a period of geologically Recent submergence. This flat is geologically an old feature. Its origin in large part at least may reasonably be attributed to the long period of erosion following early Tertiary mountain-making.

List of Publications on the Geology of the Virgin Islands

Cleve, P. T., On the geology of the northeastern West India Islands: Vetensk. Akad. Handl. 9: No. 12, 48. 1871, 2 maps.

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SPECTROSCOPY—*Regularities in the arc spectrum of vanadium.*[1]

W. F. MEGGERS, Bureau of Standards.

Kossel and Sommerfeld, in 1919, proposed the spectroscopic displacement law[2] (Verschiebungssatz) which states that the spark spectrum of any chemical element resembles in structure the arc spectrum of the element preceding it in the periodic system. This led to the alternation law[2] (Wechselsatz); that is, the even and odd structures of both arc and spark spectra alternate between adjacent columns of the periodic classification. Until recently, the validity of these laws could be tested only in the first three columns since scarcely any spectral regularities were known except for the relatively simple spectra of elements in these groups. The incomplete and inaccurate description of the more complex spectra has been responsible, in part, for the delay in finding significant regularities among them. In recent years many of these spectra have been more accurately measured in international Angstrom units, and the majority of them have had their wave-length tables extended into the red and infra-red regions, chiefly as the result of investigations by the Spec-

[1] Received July 16, 1923. Published by permission of the Director, Bureau of Standards.

[2] Sommerfeld, Atombau und Spektrallinien 3rd Ed; 456. 1922.

troscopy section of the Bureau of Standards.[3] With these more accurate and extensive data at hand this laboratory undertook to analyze the spectra of one or more elements in each of the higher columns of the periodic system, hoping thus to be able to test the proposed spectroscopic laws and to shed further light on the structure of the atom and on the nature of radiation. The same problem was independently attached by Catalán[4] and because of this coincidence the goal has been reached somewhat earlier than could otherwise have been expected.

Attention was first given to the elements with atomic numbers 19 to 26 which occupy the fourth row of the periodic system, Columns I to VIII. These elements are potassium, calcium, scandium, titanium, vanadium, chromium, manganese and iron. The arc spectra of the first two had been fairly completely arranged into series[5] for many years, but of the remainder only fragments of series were known for manganese. These latter were recently extended by Catalán[6] who also found regularities in the spark spectrum and indicated many complex groups of lines for which he coined the word "multiplet." According to Back[7] the Zeeman effect in these spectra indicates that they are in agreement with the law of alternations as outlined by Landé[8] in a paper on Termstructure and Zeeman effect of Multiplets. Regularities in the arc spectrum of chromium were discovered quite independently by Kiess[9] Gieseler,[10] and Catalán.[11] Similar investigations on the arc spectrum of molybdenum were made independently by Kiess[12] and by Catalán.[13] The results for these two elements indicate that the alternation law is valid for column VI. The first spectral regularities for any element in column VIII were found by Walters[14] in the arc spectrum of iron. Titanium, of column IV has been successfully analysed by Kiess.[15] I undertook a study of scandium and vanadium as representatives of the remaining columns III and V respectively. Wave-length data for the scandium[16] arc-

[3] Bur. Standards Scientific Papers, 312, 324, 329, 345, 372, 411, 421, 442, 466.
[4] Anales Soc. Espan. Fis. y Quim. 21: 84, 1923.
[5] Fowler, Series in Line Spectra, 1922.
[6] Phil. Trans. Roy. Soc. London A 223: 127. 1922.
[7] Zeit. f. Physik 15: 206. 1923.
[8] Zeit. f. Physik 15: 189. 1923.
[9] Science 56: 666. 1922.
[10] Ann. der Physik (IV) 69: 147. 1922.
[11] Anales Soc. Espan. Fis. y Quim. 21: 84. 1923.
[12] Bur. Standards Sci. Pap. No. 474.
[13] Anales Soc. Espan. Fis. y Quim. 21: 213. 1923.
[14] Journ. Wash. Acad. Sci. 13: 243. 1923.
[15] Journ. Wash. Acad. Sci. 13: 270. 1923.
[16] To be published in Bur. Standards Sci. Pap.

spectrum were first extended to the red and infra-red, and the analysis was practically complete when Catalán's[17] paper giving a partial explanation of both arc and spark spectra of this element appeared. My efforts were then concentrated on vanadium, and in this paper some examples of the regularities in the arc spectrum of this element are presented.

Wave-lengths of the spectral lines are taken from the measurements made by Ludwig,[18] (2400 A to 4646 A), Kiess and Meggers[19] (5500 A to 9400 A), and Exner and Haschek,[20] the latter being corrected to the international scale. Arabic and Roman numerals following each wave-length refer respectively to the intensity and temperature class of the line. King[21] made a valuable study of the variation with temperature of the electric furnace spectrum of vanadium in the region 3165 A to 6842 A. In this interval the arc intensities as estimated by King (loc. cit.) are used because he employed a larger scale (1 to 150) than the usual one (1 to 10) and made finer distinctions which are important in studying intensity rules governing lines of a multiplet. Under each wave-length is given the "frequency" or number of waves per cm. corrected to vacuum by the tables of Meggers and Peters.[22] The wave number differences or poly-fold level separations occurring in each group are given in italics between the connected pairs of lines.

Tables of the arc spectrum of vanadium contain about 2000 lines and about 15 per cent of these have now been assigned to multiplets. A few of the examples given below will require special study to settle doubtful points. For instance the lines 3184.00, 4384.73 and 4408.52 may be double. The first of these appears in multiplet 14 and from King's estimate of 60 for its intensity I have assumed it to consist of two lines of practically the same wave length and intensity. By so doing, the structure of the multiplet is completed and the distribution of intensity among its lines becomes normal. The same applies to multiplet 16 containing the line 4408.52 A to which King assigned the intensity 90. This work is still in progress, and a more detailed presentation and discussion of the results will appear later in the Scientific Papers of the Bureau of Standards. The evidence here given shows that vanadium falls into the general scheme as

[17] Anales Soc. Espan. Fis. y Quim. 20: 606. 1922.
[18] Zeit. f. Wiss. Phot. 16: 157. 1917.
[19] B. S. Sci. Papers 16: 51. 1920.
[20] Kayser, Handbuch der Spektroscopie VI.
[21] Astroph. Journ. 41: 86. 1915.
[22] Bull. Bur. Standards 14: 697. 1918.

predicted and now for the first time it can be stated positively that the alternation law of Kossel and Sommerfeld is verified for arc spectra across the entire table of chemical elements.

In order to test the displacement law, further study of spark spectra is required. Of the chemical elements mentioned above, regularities in spark spectra have been published only for potassium,[23] calcium,[5] scandium[17] and manganese.[6] A program of investigations of spark spectra has been initiated at the Bureau of Standards in order that the structures of these spectra may become known, especially for those elements the plan of whose arc spectra has now been revealed.

TABLE I—MULTIPLETS IN THE ARC SPECTRUM OF VANADIUM

Multiplet 1.

4594.10	(60, I)	4577.18	(40, I)				
21760.96	*80.47*	21841.43					
		137.40					
		4606.15	(15, I)	4580.40	(40, I)		
		21704.03	*122.01*	21826.04			
		186.07		*186.08*			
		4645.98	(1, IIIA)	4619.79	(25, I)	4586.37	(50, I)
		21517.96	*122.00*	21639.96	*157.99*	21797.65	
						229.54	
						4635.18	(15, I)
						21568.11	

Multiplet 2.

4851.51	(40, I)	4832.43	(30, I)	4799.70	(5, IIA)		
20606.41	*81.34*	20687.75	*104.68*	20828.43			
		137.33		*137.31*			
		4864.73	(40, I)	4831.64	(35, I)	4784.50	(5, IIA)
		20550.42	*140.70*	20691.12	*203.90*	20895.02	
				186.00		*185.90*	
				4875.47	(40, I)	4827.45	(30, I)
				20505.12	*204.00*	20709.12	
						229.53	
						4881.55	(50, I)
						20479.59	

[23] Nissen. Astroph. Journ. 57: 185. 1923.

Multiplet 3.

8198.85	(3)	8144.52	(3)				
12193.49	*81.33*	12274.82					
63.25		*63.26*					
8241.60	(4)	8186.71	(3)	8093.47	(2)		
12130.24	*81.22*	12211.56	*140.70*	12352.26			
		102.33		*102.31*			
		8255.90	(4)	8161.03	(4)	8027.34	(2)
		12109.23	*140.72*	12249.95	*204.07*	12454.02	
				137.18		*137.24*	
				8253.48	(4)	8116.78	(5)
				12112.77	*204.01*	12316.78	

Multiplet 4.

4330.03	(30, I)	4307.19	(12, I)				
23088.04	*122.46*	23210.50					
137.40		*137.37*					
4355.96	(10, I)	4332.83	(30, I)	4306.22	(15, I)		
22950.64	*122.49*	23073.13	*142.57*	23215.70			
		186.01		*186.07*			
		4368.05	(10, I)	4341.02	(40, I)	4309.80	(20, I)
		22887.12	*142.51*	23029.63	*166.79*	23196.42	
				229.59		*229.61*	
				*4384.73	(125, II)	4352.89	(50, I)
				22800.04	*166.77*	22966.81	

Multiplet 5.

6812.42	(2, IIIA)						
14675.02							
63.21							
6841.90	(1, IIIA)	6785.02	(3, IIIA)				
14611.81	*122.48*	14734.29					
		102.32					
		6832.47	(1, IIIA)	6766.53	(4, IIIA)		
		14631.97	*142.59*	14774.56			
				137.13			
				6829.92	(1, IIIA)	6753.03	(5, IIIA)
				14637.43	*166.66*	14804.09	

Multiplet 6.

3855.37	(30, I)	3844.44	(20, I)				
25930.53	*73.70*	26004.23					
137.43		*137.38*					
3875.91	(20, I)	3864.86	(35, I)	3847.33	(20, I)		
25793.12	*73.73*	25866.85	*117.84*	25984.69			
		186.08		*186.06*			
		3892.86	(25, I)	3875.08	(35, I)	3841.89	(5, IA)
		25680.77	*117.86*	25798.63	*222.87*	26021.50	
				229.68		*229.55*	
				3909.89	(20, I)	3876.08	(20, I)
				25568.95	*223.00*	25791.95	

Multiplet 7.

5706.98	(30, I)						
17517.55							
63.26							
5727.67	(20, II)	5703.59	(40, I)				
17454.29	*73.67*	17527.96					
102.34		*102.17*					
5761.45	(2, IIIA)	5737.03	(25, II)	5698.49	(60, I)		
17351.95	*73.84*	17425.79	*117.85*	17543.64			
		137.28		*137.29*			
		5782.59	(2, IIIA)	5743.44	(18, II)	5670.83	(30, I)
		17288.51	*117.84*	17406.35	*222.87*	17629.22	

Multiplet 8.

3781.40	(1, II)	3771.66	(1, IA)				
26437.76	*68.25*	26506.01					
		137.50					
		3791.33	(2, IA)	3777.17	(2, IA)		
		26368.51	*98.88*	26467.37			
				186.00			
				3803.90	(6, IA)	3784.68	(2, IA)
				26281.37	*133.50*	26414.87	
						229.49	
						3817.85	(8, IA)
						26185.38	

Multiplet 9.

4109.78	(50, I)						
24325.36							
40.88							
4116.70	(4, IA)	4105.17	(60, I)				
24284.48	*68.22*	24352.70					
66.93		*66.93*					
4128.08	(60, I)	4116.48	(50, I)	4099.80	(60, I)		
24217.55	*68.22*	24285.77	*98.83*	24384.60			
		91.32		*91.15*			
		4132.02	(60, I)	4115.18	(60, I)	4092.69	(50, I)
		24194.45	*99.00*	24293.45	*133.46*	24426.91	
				113.52		*113.44*	
				4134.50	(60, I)	4111.79	(100, I)
				24179.93	*133.54*	24313.47	

Multiplet 10.

3835.56	(4, II)	3826.77	(6, II)				
26064.43	*59.88*	26124.31					
63.21		*63.23*					
3844.89	(4, II)	3836.06	(5, I)	3823.98	(5, II)		
26001.22	*59.86*	26061.08	*82.32*	26143.40			
		102.30		*102.31*			
		3851.17	(5, I)	3839.00	(10, I)		
		25958.78	*82.31*	26041.09			
				137.22			
				3859.34	(6, II)		
				25903.87			

Multiplet 11.

2899.60	(8)	2894.58	(5)	2887.71	(1)		
34477.40	*59.79*	34537.19	*82.24*	34619.43			
		137.27		*137.32*			
		2906.98	(8)	2899.21	(8)	2888.52	(1)
		34399.92	*82.19*	34482.11	*127.53*	34609.64	
				185.90		*185.93*	
				2914.92	(10)	2904.13	(8)
				34296.21	*127.50*	34423.71	
						229.60	
						2923.63	(10)
						34194.11	

Multiplet 12.

4090.59	(25, I)						
24439.50							
166.52							
4118.65	(8, III)	4095.48	(25, II)				
24272.98	*137.29*	24410.27					
142.12		*142.09*					
4142.91	(2, III)	4119.46	(8, III)	4102.16	(20, II)		
24130.86	*137.32*	24268.18	*102.35*	24370.53			
		78.88		*78.88*			
		4132.90	(?)	4115.48	(2, III)	4104.78	(15, III)
		24189.30	*102.35*	24291.65	*63.35*	24355.00	

Multiplet 13.

3050.88	(3, R)	3043.55	(3, R)				
32767.90	*78.90*	32846.80					
137.33		*137.38*					
3063.72	(3)	3056.34	(3, R)	3043.12	(3, R)		
32630.57	*78.85*	32709.42	*142.02*	32851.44			
		186.07		*186.04*			
		3073.82	(3, R)	3060.46	(3, R)	3044.94	(4, R)
		32523.35	*142.05*	32665.40	*166.47*	32831.87	
				228.48		*229.49*	
				?3082.02	(4)	3066.37	(3, R)
				32436.92	*165.46*	32602.38	

Multiplet 14.

†3184.00	(25r, II)						
31398.06							
137.63							
3198.01	(20, II)	†3183.42	(30r, II)				
31260.43	*143.35*	31403.78					
185.61		*186.02*					
3217.11	(10, II)	3202.38	(25, II)	†3184.00	(35R, II)		
31074.82	*142.94*	31217.76	*180.30*	31398.06			
		229.56		*229.27*			
		3226.11	(4, II)	3207.42	(20, II)	†3185.40	(40R, II)
		30988.20	*180.59*	31168.79	*215.38*	31384.17	

Multiplet 15.

		4436.14	(15, I)								
		22535.82									
		40.95									
4452.02	(20, III)	4444.22	(20, I)	4428.52	(15, I)						
22455.42	*39.45*	22494.87	*79.72*	22574.59							
		66.96		*66.92*							
		4457.48	(15, I)	4441.69	(25, I)	4419.94	(12, I)				
		22427.91	*79.76*	22507.67	*110.71*	22618.38					
				91.25		*91.20*					
				4459.77	(30, I)	4437.84	(20, I)	4412.14	(12, I)		
				22416.43	*110.75*	22527.18	*131.21*	22658.39			
						113.43					
						4460.30	(50, I)				
						22413.75					

Multiplet 16.

4408.52	(45, I)	4400.59	(60, II)								
22677.01	*40.86*	22717.87									
40.88		*40.86*									
4416.48	(20, I)	4408.52	(45, I)	4395.24	(80, II)						
22636.13	*40.88*	22677.01	*68.50*	22745.51							
		67.01		*66.90*							
		4421.58	(20, I)	4408.21	(70, I)	4389.99	(100, II)				
		22610.00	*68.61*	22678.61	*94.13*	22772.74					
				91.22		*91.29*					
				4426.01	(20, I)	4407.66	(70, I)	4384.73	(125r, II)		
				22587.39	*94.06*	22681.45	*118.61*	22800.04			
						113.39		*113.41*			
						4429.80	(15, I)	4406.65	(80, I)	4379.24	(150r, II)
						22508.06	*118.57*	22686.63	*141.98*	22828.61	

* *Cf.* Multiplet 16. † Raies ultimes.

PHYSICS—*A comparison of the heating-curve and quenching methods of melting-point determinations.*[1] GEORGE W. MOREY. Geophysical Laboratory, Carnegie Institution of Washington.

The temperature of equilibrium between liquid and solid phases of a pure substance, or of the beginning or end of melting in a mixture, is a datum point frequently determined, and any information bearing on its determination is of interest to the investigator. The following experiments were carried out to compare the heating-curve method, which is the method followed almost exclusively in the study of metals and of salts which crystallize readily, with the quenching method, used chiefly in the study of substances which are difficult to crystallize, such as the silicate minerals. In the latter method, a tiny charge, of a few milligrams, is wrapped in thin platinum foil, and held at a definite temperature until equilibrium is reached. The charge is then suddenly cooled, sometimes by dropping into mercury, sometimes by merely lifting out of the furnace, and examined under the microscope. If the heating has been above the melting-point, the examination will show only glass; if below the melting-point, only crystals; and repetition at the same temperature for varying times will show how long it is necessary to wait for equilibrium. This method is the choice of all familiar with it, whenever it can be applied, because of the unequivocal nature of the evidence it supplies; it is, however, only applicable to substances which are sluggish crystallizers, such as the silicates, borates, and phosphates, and is not applicable to most salts.

In the case of the silicate minerals, cooling-curves are rarely of value, because of the great tendency toward undercooling, and the use of heating-curves is made difficult by the same sluggishness. In metals and in easily crystallizable salts such as sodium sulfate the heating-curve shows a sharp break both at the beginning and end of melting, and usually an actually flat portion between. In the case of the silicate minerals the heating-curve is rarely sharply broken, and often is oblique. The causes of the obliquity have been fully discussed by White;[2] but the exact location of the melting-point remains a matter of some difficulty. It therefore seemed desirable to compare the two methods on a substance which gives a fair heating-curve, and also enables the melting-point to be located exactly by means of quenches. Sodium metasilicate is such a substance, and accordingly

[1] Received July 11, 1923.

[2] W. P. White, Am. Journ. Sci. 28: 453–73. 1909.

a series of quenches and of heating-curves were run on a sample of sodium metasilicate containing a slight excess of SiO_2, analysis giving a ratio of SiO_2 to Na_2O of 1.007. Heating curves were made with a

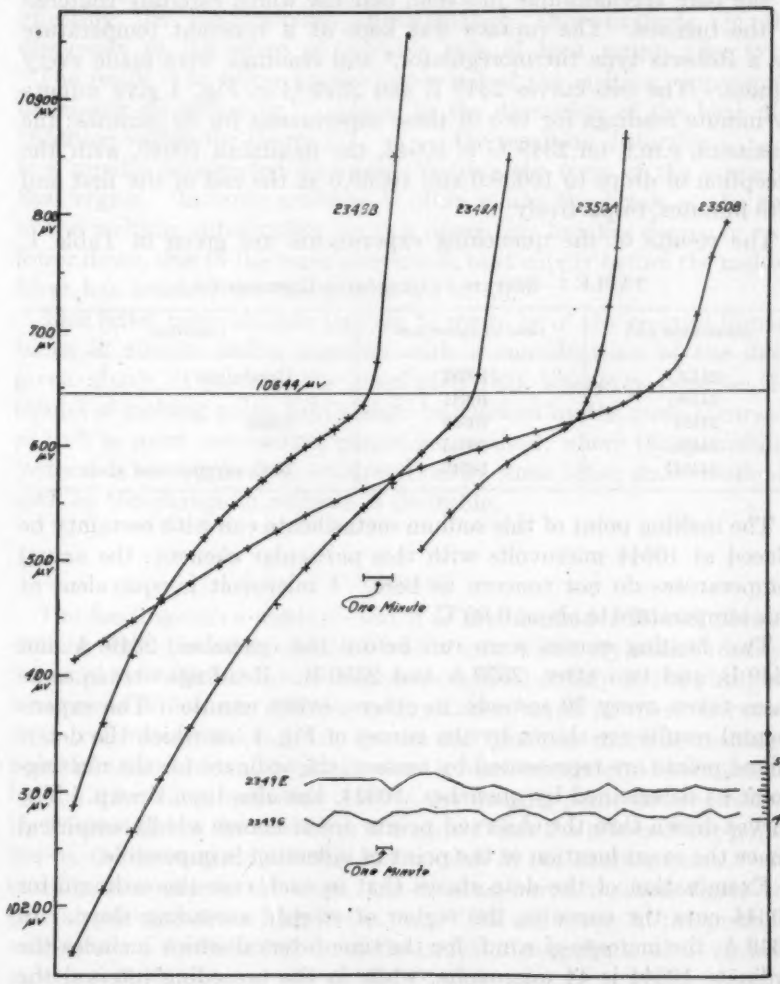

Fig. 1. Curves obtained on heating a charge of sodium metasilicate at various rates

bare platinum-platinrhodium thermocouple. The charge was contained in a thimble crucible of platinum, 1 cm. in diameter and 2 cm. deep,

and the furnace used had a zone of 4 cm. in which the temperature was uniform to one degree.

In the quenching experiments the charge was placed within 1 mm of the bare thermocouple junction, and the whole carefully centered in the furnace. The furnace was kept at a constant temperature by a Roberts type thermoregulator,[3] and readings were made every minute. The two curves 2349 E and 2349 G in Fig. 1 give minute by minute readings for two of these experiments for 30 minutes; the maximum e.m.f. on 2349 G is 10642, the minimum 10640, with the exception of drops to 10639.0 and 10639.5 at the end of the first and fifth minutes, respectively.

The results of the quenching experiments are given in Table 1.

TABLE 1—RESULTS OF QUENCHING EXPERIMENTS

EXPERIMENT NO.	TEMP. IN MICROVOLTS	CONDITION
2449C	10632	Crystalline
2449G	10641	"
2449F	10650	Glass
2449E	10645	"
2449D	10643	Both crystals and glass

The melting point of this sodium metasilicate can with certainty be placed at 10644 microvolts with this particular element; the actual temperatures do not concern us here. 1 microvolt is equivalent at this temperature to about 0.09°C.

Two heating curves were run before the quenches, 2349 A and 2349 B, and two after, 2350 A and 2350 B. Readings were in some cases taken every 30 seconds, in others, every minute. The experimental results are shown by the curves of Fig. 1, on which the determined points are represented by crosses; the ordinate for the melting-point as determined by quenches, 10644, has also been drawn. The curves drawn thru the observed points are of course wholly empirical hence the exact location of the point of inflection is impossible.

Examination of the data shows that in each case the ordinate for 10644 cuts the curve in the region of steeply ascending slope. In 2349 A, the increase of e.m.f. for the time interval which includes the ordinate 10644 is 44 microvolts, while in the preceding interval the e.m.f. increased 23 microvolts; similarly, in 2349B, the increments are 38 and 11; in 2350A, 17 and 9; in 2350B, 10 and 8. The precise location

[3] H. S. Roberts. This Journal 11: 401. 1921.

of the melting-point from these curves is, however, arbitrary, and comparison with the quenching experiments shows that in most cases the tendency is to put the melting-point too low. This is the effect to be expected from the discussion given by White of the factors affecting the melting-point determination. For example, in the discussion of the effect of variable rate of heat supply,[4] he says: "The result is to hurry up the latter end of the melting, apparently increasing its obliquity." Again, in the discussion of the heat distribution within the charge,[5] ". . . the resulting distortion . . . is a rapidly accelerated increase, changing the form of the curve in that region. In large crucibles it often masks the break at the end of the melting, substituting for it a premature break a degree or two lower down, due to the rapid increase in heat supply before the melted layer has touched the thermoelement at all."

This latter consideration appears to me to be of the greatest importance in silicate melts; together with a consideration of the data given above, it justifies the conclusion that whenever possible the results of melting-point data should be checked by the more accurate, as well as more convenient, quenching method; where the quenching method is not applicable, confirmation by some other static method, such as the change in volume, is desirable.

SUMMARY

The heating-curve method, which is the method followed almost exclusively in the study of metals and of salts which crystallize readily, is compared with the quenching method, used chiefly in the study of substances which are difficult to crystallize, such as most silicates. It is well recognized both in theory and practise that the melting-point of a substance of the latter class is more accurately determinable by the quenching method. Taking the melting-point determination by this method as the standard, it is shown that the true melting-point lies on the more rapidly rising end portion of the heating curve. As usually interpreted, therefore, the heating-curve method tends to give a melting-point which is too low. The difference in the present case (sodium metasilicate) is of the order of magnitude of 2° or less at about 1100°.

[4] Op. cit., p. 461.
[5] Op. cit., p. 464.

CHEMISTRY—*The residue from silica in rock-analysis.*[1] M. AUROUSSEAU. (Communicated by H. S. WASHINGTON.)

The usual procedure in rock-analysis, when dealing with the "main portion" is to decompose about one gram of the rock powder by fusion with five times its weight of sodium carbonate. The cake is brought into chloride solution, the solution evaporated to dryness and the silica separated and washed by cold filtration. The silica is then ignited in a weighed platinum crucible, weighed, driven off by hydrofluoric acid, and the crucible and residue which it invariably contains are again weighed after ignition. Hillebrand and Washington have both commented on the amount and nature of this residue, and Bloor has investigated it in connection with the analysis of clays—a somewhat different process from the analysis of rocks.[2]

Both Hillebrand and Washington agree that the residue is of constant occurrence, that it differs in nature and in quantity with different kinds of rocks, and that it contains chiefly oxides of titanium, iron, and phosphorus. The former states that it is quantitatively precipitable with ammonia, and that it should contain little if any lime or magnesia if the rock has been properly decomposed. This is not in agreement with Bloor's results. His residues were complex in composition, and many of them contained lime and magnesia in notable quantity. No statement of the quantitative composition of the residues obtained in *rock* analysis has ever been published. Hillebrand states that he has tested residues, after the appearance of Bloor's paper, and is not able to substantiate Bloor's results. In my experience, the behavior of similar rocks is very irregular, even under conditions of work subject to little variation. For example, in analyzing a series of basalts from Etna, the residues obtained were unlike in quantity and appearance. Taking all precautions to ensure complete decomposition, the residue sometimes indicates that this was not attained.

While analyzing the new material (a silicic andesite) which rose in the crater of Lassen Peak, Cal., during its period of activity since 1914, opportunity was afforded to collect and analyze the residue from the silica of an andesite. One incomplete and two complete

[1] Received July 12, 1923.

[2] Hillebrand, W. F. The analysis of silicate and carbonate rocks. U. S. G. S., Bull. 700, 1919, pp. 104–105, and 119 (first footnote).

Washington, H. S. The chemical analysis of rocks, 3rd. Ed., New York, 1919, p. 146.

Bloor, W. R. Journ Am. Chem. Soc., 29, 1907, p. 1603.

analyses of different modifications of the rock were executed. They indicated only the slightest variation in composition, any one of them being quite representative of the rock. These results will doubtless be published elsewhere, and therefore the average of the three will be used here. In addition, a number of determinations of ferrous and total iron were made on the same material, the latter providing the residues examined.

Three portions, amounting to 3.0008 grams, of rock powder provided 0.0165 gram of residue. This was obtained by three separate fusions, carried out under identical conditions. Nevertheless, the third fusion, judging from the appearance of the residue, was not as effective as the others. After expelling the hydrofluoric and sulphuric acids, the residues were ignited for an hour in the electric furnace at a temperature of 850°C., in an oxidizing atmosphere. They were collected, after weighing, by ordinary sodium carbonate fusion, and were analyzed in the usual way, except for the deviations required for MnO and P_2O_5. The composition of the residue by weight was found to be as follows:

	grams
Al_2O_3	0.0021
Fe_2O_3	0.0041
CaO	0.0003
MgO	0.0026
TiO_2	0.0049
P_2O_5	0.0003
MnO	none
SO_3	0.0013
Undetermined	0.0009
Total	0.0165

The residue thus consists principally of the oxides of titanium, iron, magnesium, and aluminium. The quantity of MgO and the presence of SO_3 are somewhat surprising.

The interest and significance of the composition of the residue, for the analyst, lies in its relation to the composition of the rock. On a percentage basis, the constituents determined amount to 0.52 per cent of the rock (column 2, table 1). If the amount of each oxide in the residue be compared with the amount of the corresponding oxide in the rock, it is evident from column 3 of table 1 that TiO_2, MgO, and Fe_2O_3 (the relation is to total iron) have here shown the greatest tendency to remain behind in the residue. It is to be noted that only a negligible proportion of the P_2O_5 remained behind, and relatively little alumina. The subjoined table expresses the results clearly.

The complexity of the composition of the residue raises the question of its recovery. Fortunately this offers no difficulty and takes place during the subsequent course of analysis. The precipitate thrown down by ammonia in the filtrate from silica is ignited and weighed in the same crucible as the residue, when fusion with potassium pyrosulphate renders all the iron, alumina, titanic oxide, and phosphorus available for determination. Lime and magnesia, and possibly a little baria are not recovered, unless great accuracy is required. The amount of lime or baria the residue is likely to contain is negligible,

TABLE 1

	1	2	3
SiO_2	63.54		
Al_2O_3	16.93	0.07	0.4
Fe_2O_3	1.69	0.14	3.8
FeO	2.67		
MgO	2.77	0.09	3.3
CaO	5.07	0.01	0.02
Na_2O	4.08		
K_2O	2.18		
H_2O+	0.22		
H_2O-	0.04		
TiO_2	0.51	0.16	31.4
P_2O_5	0.14	0.01	0.7
SO_3		0.04	
S	0.02		
MnO	0.07		
BaO	0.07		
Sum	100.00	0.52	

1. Andesite. The Crater, Lassen Peak, California. The new lava of 1915. Average of one incomplete and two complete analyses. M. Aurousseau, analyst.
2. Oxides of the residue from silica, expressed as percentages of the rock.
3. Oxides of the residue expressed as percentages of the corresponding oxides of the rock.

and in a rock of the kind studied here the small amount of magnesia has but a slight effect on the final result, and its recovery is unimportant for any but the most exacting work.

The examination of the residue from silica in rock analysis is troublesome and inconvenient. The amount is small, and must be collected specially, if required for study. It is none the less highly desirable that residues from a wide range of rock composition (say from granite, diorite, basalt, nephelite syenite, and peridotite) be examined systematically, in order that some general conclusion might be drawn concerning the nature and behavior of the residue.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

PHILOSOPHICAL SOCIETY OF WASHINGTON

886TH MEETING

The 886th meeting was held in the Cosmos Club Auditorium on Saturday, May 5, 1923. It was called to order at 8:15 p.m. by President WHITE with 35 persons in attendance.

The first paper, *Free-air pressure maps and their accuracy*, was presented by Mr. C. LEROY MEISINGER. The paper was illustrated by lantern slides and was discussed by Messrs. WHITE, LITTLEHALES, TUCKERMAN, HAWKESWORTH, HUMPHREYS, PAWLING, and GREGG.

Author's abstract: The variations of barometric pressure from day to day are of fundamental importance to the weather forecaster; but before the barometric readings can be compared, they must be reduced to some common level. At present, sea-level is the only reduction level in use, and for stations of no great elevation above this level the barometric indications correspond closely with surface weather conditions. But in high elevations the sea-level reductions are less satisfactory. The physical advantage of reduction upward to a free-air level is that horizontal barometric gradients correspond closely to the air movement at the same level. Moreover, the mean temperature of the air column (an important term in the hypsometric equation) is a real quantity in contrast with its fictitious nature when the reduction is downward.

The difficulties of securing current observations of the average temperature of the air column at a sufficiently large number of stations and of reducing them in time to be of current usefulness to the forecaster, necessitate the use of some regularly-observed surface weather element as an index to this quantity.

It was found upon analyzing a large body of aerological data that the difference between the mean temperature of the air column and the surface temperature varied markedly with surface wind direction and the season. A classification of these data in this manner enabled one to ascertain the geographical distribution and further to interpolate for non-aerological stations in the construction of tables for barometric reductions.

During the three months, December 1922 to February 1923, inclusive, daily post-card reports of 8 a.m. (75th meridian time) pressure at 1 and 2 kilometers (3281 and 6562 feet) above sea-level were made by 29 stations within the area embraced by the six aerological stations of the Weather Bureau. A statistical investigation of the accuracy of the reductions was made from two classes of data:

(1) Computed free-air pressures compared with pressures measured by kites at the aerological stations showed that 73% of the computations agreed within 0.05 inch. (Isobars on the daily weather map are drawn for intervals of 0.10 inch.)

(2) Wind directions in the free-air estimated upon the basis of the gradient wind relations, were compared with wind directions actually observed by means of pilot balloons, and it was found that the estimated wind was correct in 63% of the cases and the direction-error did not exceed 90° in 89% of the cases. It was discovered further that the average wind velocity for the various classes of error decreased markedly with increase of error, thus indicating that large errors of estimation were associated with very light winds and were, therefore, of little practical significance.

One of the outstanding uses of these charts is in connection with the supplying of free-air information to aviators at times when, through interference by large areas of clouds, pilot balloon observations are not possible. The practical utility of the charts for forecasting general weather must be determined after subjecting them to continuous comparison and study by experienced forecasters. The experience of the Japanese, however, with similar maps constructed somewhat differently has indicated that there are advantages for general forecasting. The fact that the degree of reliability of these maps is high, as indicated by the study of their accuracy, shows that, in any event, they afford a basis for studies relating to the physical processes within the lowest 2 kilometers of the atmosphere.

The second paper, *Air Navigation*, was presented by Mr. J. P. AULT. The paper was illustrated with lantern slides, and was discussed by Messrs. HEYL, LITTLEHALES, and HUMPHREYS.

Author's abstract: The method which has been used for the most part up to the present time in air navigation has been by dead reckoning. For cross-country flying and short flights over the water, a good compass and a good map are the two most important instruments required.

For long-distance flying, however, the aviator should be able to locate his position by some other means as, for example, by astronomical observations or by directional radio bearings, when he is unable to see objects on the ground during night flights or while flying above clouds or fog, or ocean.

The present paper described work which was done during the latter months of 1918 at Langley Field in the attempt to develop methods and instruments for navigating airplanes by astronomical observations. The problem is essentially the same as at sea to determine the position of a ship. Various experiments were made using the natural horizon, either land, sea, cloud, or haze, but these horizons will not always be available for the aviator. Some form of artificial horizon must be provided. Observations with a preliminary pendulum-type horizon gave results where the probable error of a single observation of the altitude of some celestial body amounted to $\pm 12'$ on the average.

Various methods of computing the results were tried, and special instruments for plotting the resulting position-line were developed.

A sextant with some form of artificial-level attachment, either pendulum or bubble, was found to be superior to the preliminary pendulum-type artificial horizon.

It became apparent that, when only one celestial body is available for observation, it would be necessary also to measure the azimuth of this body in addition to the altitude. Experiments along this line gave surprisingly good results. Azimuths of the sun could be determined with a probable error of ± 0.3 for means of 10 observations. Thus with some of the methods of reduction which are available, it will not be necessary for the aviator to know his dead-reckoned position very accurately if he is able to measure both the azimuth and the altitude of the celestial body.

Owing to the difficulties of navigation by astronomical methods and to the fact that frequently no celestial body can be seen on account of clouds or other conditions, the third method of navigation by some directional radio device seems to be the most promising as a solution of the problem. This method is as yet in the experimental stage.

887TH MEETING

The 887th meeting was held at the Cosmos Club Auditorium on Saturday, May 19, 1923. It was called to order at 8:15 p.m. by President WHITE with 60 persons in attendance.

President White commended the outgoing Program Committee for their splendid work during the year and announced the appointment of the new Program Committee for 1923–1924 as follows: Messrs. HEYL (Chairman), GISH, and MEISINGER.

A paper entitled *The Alchemist* was presented by Dr. PAUL D. FOOTE. It was illustrated with lantern slides and was discussed by Messrs. HAWKESWORTH, BRIGGS, RUARK, TUCKERMAN, WHITE, HUMPHREYS, and WILLIAMSON.

Author's abstract: A historical summary of the early alchemical literature was briefly presented. The elaborate experiments of these pseudo-investigators contributed somewhat to the progress of chemistry, but no transmutations of the elements were effected. Alchemy as a sound physical hypothesis had its origin within the past twenty years, and its possibility became evident with the modern development of our knowledge of atomic structure.

An atom consists of a planetary system of electrons revolving about a positively charged nucleus or sun. The nucleus or sun itself is a complicated structure, probably of a planetary nature, consisting of a group of closely bound hydrogen nuclei, helium nuclei, and electrons. The sun in a gold atom, for example, contains 49 helium suns, one extra hydrogen sun, and 20 electrons, all packed in the space of 30 billionth billionth billionth billionths of a cubic centimeter. Alchemy is concerned with the disintegration of these minute nuclear suns.

We have about 40 different radioactive species which are produced spontaneously and which represent transmutations of the elements in the strictly alchemical sense. Many radioactive elements give off helium. Some of the light elements may be transmuted into still lighter elements and hydrogen—the recent experiments of Rutherford in which the disintegration is produced by bombardment with alpha particles. Rutherford has stated that very likely every element may be transmuted as soon as the scientist is able to utilize an electric field of 10 million volts.

It seems probable that transmutation of baser metals into gold, platinum, and other rare metals may be effected on a small scale by several methods which were outlined and which were analogous to spontaneous radioactive disintegration or to the artificial disintegration by the Rutherford method. Such alchemical transformations on a large scale of production is, however, a problem for the distant future. It was pointed out that when that time comes, the problem of transmutation for the object of producing rare metals will shrink to insignificance compared to the greater interests which will develop simultaneously. For by whatever means quantity production is effected, the same methods can be employed in the creation of energy by the annihilation of mass. Thus if the hydrogen in two teaspoonsful of water were converted into helium, an amount of energy is liberated equivalent to $20,000 worth of electrical power at the current rates.

J. P. AULT, *Recording Secretary.*

SCIENTIFIC NOTES AND NEWS

The twenty-fourth biennial edition of the Directory of the Washington Academy of Sciences has just been issued. This contains the names and and addresses of members of the ACADEMY and of each of the 16 affiliated societies. A list of the scientific and technical societies of Washington which are not affiliated with the ACADEMY, and of national societies having headquarters or offices in Washington, is also included.

The following persons have become members of the ACADEMY since the last report in the Journal (August 19, 1922, p. 341). Except when otherwise noted the address is Washington, D. C.

C. W. LARSON, M. G. LLOYD, A. P. HITCHENS, W. L. CHENEY, E. W. BRANDES, F. H. SMYTH, F. W. SMITHER, G. E. F. LUNDELL, F. LA FLESCHE, V. BIRCKNER, L. L. STEELE, E. R. WEIDLEIN, University of Pittsburgh, Pittsburgh, Pa., W. S. FRANKLIN, Massachusetts Institute of Technology, Cambridge, Mass., A. T. PIENKOWSKY, H. S. ROBERTS, R. W. BALCOM, H. B. BROOKS, E. C. ECKHARDT, A. C. HUNTER, WILSON POPENOE, A. O. TOOL, E. A. GOLDMAN, E. R. WEAVER, EDWARD WICHERS, P. H. BATES, R. K. BEATTIE, R. F. JACKSON, J. B. S. NORTON, College Park, Md., W. F. STUTZ, J. M. SHERMAN, F. B. LAFORGE, W. A. SLATER, Urbana, Ill., A. C. BÖVING, R. H. DALGLEISH (reinstated), W. M. CORSE, E. P. KILLIP, C. G. PETERS, L. H. REICHELDERFER, H. SHAPLEY, Harvard Observatory, Cambridge, Mass., G. STEINER, O. P. HOOD, A. R. CHEYNEY, and W. P. WHITE.

Dr. RAUL GAUTIER, Director of the Observatory and Professor in the University of Geneva, Switzerland, was recently elected to honorary membership in the Washington Academy of Sciences in recognition of his prominence in geodesy and his intimate connection with scientific work in Washington.

The experimental research laboratory of the Navy Department, authorized by act of Congress in August, 1916, was formally placed in commission on July 2, 1923. The subjects studied at the laboratory will include: Gun erosion, torpedo motive power, the gyroscope, submarine guns, protection against submarine, torpedo and mine attack, improvement in submarine attachments, improvement and development in submarine engines, storage batteries and propulsion, aeroplanes and aircraft, improvement in radio installations, and other necessary work of the Government service. The laboratory is situated at Bellevue, D. C.

Dr. GEORGE N. ACKER died in Washington on July 22, 1923, in his seventy-first year. He was born in Washington, D. C., October 5, 1852. Dr. Acker was educated at Pennsylvania College, Columbian University (now George Washington University) and the University of Berlin. He held various positions on the medical staff of George Washington University from 1880 until his death. He was a member of the ACADEMY, Anthropological Society of Washington, and the Medical Society of the District of Columbia as well as many other medical societies.

The office of chief of the Bureau of Chemistry, which has been vacant since the resignation of Dr. C. L. ALSBERG in July, 1921, has been filled by

the appointment of Dr. C. A. BROWNE. Dr. Browne has for the past sixteen years been head of the New York Sugar Trade Laboratory and previously was chief of the sugar laboratory at the Bureau of Chemistry.

Non-political interests view with dismay the action of Dr. Hubert Work, Secretary of the Interior, in dismissing Mr. A. P. DAVIS and appointing in his place as director of the Reclamation Service former Gov. Davis of Idaho. Protests have been filed at the Interior Department by engineering and water-power organizations.

Dr. D. R. HARPER, physicist, U. S. Bureau of Standards, Washington, D. C., has been detailed to New York for service as liaison officer between the Bureau of Standards and the American Engineering Standards Committee in the Engineering Societies Building, New York City, succeeding Dr. A. S. MCALLISTER of the Bureau of Standards, recalled from New York to Washington. Dr. McAllister takes charge of part of Secretary Hoover's special work in relation to commodity standards and specifications, inaugurated recently under the Bureau of Standards.

Mr. W. E. MYER of the Smithsonian Institution has returned from Tennessee where for the past two and a half months he has been excavating the Great Mound Group in Cheatham county. He found traces of an important ancient town covering about 500 acres in two adjoining bends of Harpeth river. Many earth-lodge sites were excavated which yielded a considerable amount of information as to the life of the former inhabitants.